HNUE JOURNAL OF SCIENCE
Natural Sciences 2025, Volume 70, Issue 1, pp. 140-154
This paper is available online at http://hnuejs.edu.vn/ns
DOI: 10.18173/2354-1059.2025-0015

INTEGRATING MODIS SATELLITE DATA AND GOOGLE EARTH ENGINE IN DROUGHT MONITORING IN NINH THUAN PROVINCE, VIETNAM

Le Thanh Khong and Tran Thi An*
Faculty of Natural Resources and Environment, Thu Dau Mot University, Binh Duong Province, Vietnam
*Corresponding author: Tran Thi An, e-mail: antt@tdmu.edu.vn

Received October 25, 2024. Revised March 4, 2025. Accepted March 31, 2025.

Abstract. This study aims to assess the current drought situation in Ninh Thuan province, Vietnam, using remote sensing and GIS technology. Using the Google Earth Engine cloud-based computing platform, the authors calculated the drought indices for Ninh Thuan province using remote sensing indicators extracted from MODIS satellite data, including Land Surface Temperature and Normalized Difference Vegetation Index. Combined with GIS and remote sensing tools, the study has developed a process for calculating dry indicators: Temperature Condition Index, Vegetation Condition Index, and Vegetation Health Index. Subsequently, the study generated the drought hazard map of Ninh Thuan province based on the VHI drought index with drought levels from extreme to no drought. Results indicate that the drought severity has been increasing gradually since 2000 and has become dominant in 2005, with the drought levels from moderate to extreme occupying an area of 187,724.75 ha, and equal to 56 percent of the study area. Spatially, severe and extreme drought conditions are primarily found in the coastal plains, particularly in the districts of Thuan Bac, Thuan Nam, Ninh Hai, Ninh Phuoc, and Phan Rang - Thap Cham. In contrast, drought intensity decreases in the western districts, such as Bac Ai and Ninh Son. The research also examined drought levels in relation to agricultural areas in Ninh Thuan province, thereby assessing the impact of drought on the province's agricultural sector in the context of climate change.

Keywords: drought assessment, Google Earth Engine, MODIS satellite, Ninh Thuan.

1. Introduction

Ninh Thuan is a coastal province in the South Central Coast of Vietnam. This area is considered the region with the harshest weather conditions in Vietnam. Annually, the rainfall is not large and unevenly distributed spatially and temporally, so the moisture shortage of Ninh Thuan province is very high. In recent years, the phenomenon of water shortage and the expansion of wasteland has been threatening the lives of local citizens, affecting the socio-economic conditions, especially the agricultural sector.

Previously, the assessment of drought hazard was mainly based on data from meteorological monitoring stations, causing many difficulties in monitoring and assessing drought due to the lack of field measurement data. The development of space technology brings a wide range of supplementation to the source of Earth observational satellite data with high accuracy and regularly updated. The use of Geographical Information System (GIS) and remote sensing data in monitoring drought hazard has been widely applied in many countries around the world, meeting the practical need to promptly take effective measures to respond to the drought impacts in the study area. The application of remote sensing and GIS to analyze and assess natural disasters, as well as drought hazard, is increasingly used worldwide. Thanks to the relatively high accuracy and cost-effectiveness compared to traditional methods, the application of GIS technology and remote sensing in drought studies is increasing globally [1]-[5].

While there are various remote sensing data currently used in drought hazard assessment, the use of MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data in drought research presents several advantages [6]. MODIS provides near-daily observations, allowing researchers to monitor drought conditions frequently and capture rapid changes in the environment [7]. Moreover, MODIS offers a wide range of data products, such as vegetation indices, land surface temperature, and surface reflectance. These products are crucial for assessing vegetation health and soil moisture dynamics during drought periods. Especially, the data from MODIS is freely available, which allows all researchers and organizations involved in drought monitoring and assessment [6]-[8].

Numerous tools have been developed to facilitate the analysis of satellite imagery. Google Earth Engine (GEE), which is a cloud computing platform, has been publicly used recently to process satellite imagery and other geospatial data. It provides free access to a huge database of satellite images and the algorithms needed to analyze remotely sensed data. GEE allows monitoring of changes in the fields of agriculture, water resources, and climate using geospatial data with different levels of spatial and temporal resolution [9]. It provides a catalog of data along with analytical algorithms, allowing different groups of users, such as researchers and environmental resource experts, to collaborate using data, algorithms, and visual illustrations. Based on the study area conditions and the advantages of remote sensing applications in drought monitoring, the authors conducted the study on "*Integration of MODIS satellite data and Google Earth Engine in drought assessment in Ninh Thuan province, Vietnam*". The integration of MODIS satellite data with Google Earth Engine has significantly enhanced the ability to assess and monitor drought conditions in Ninh Thuan province, Vietnam. This approach not only increases processing efficiency and accuracy but also provides valuable insights for local decision-makers and stakeholders involved in drought management and response.

2. Content

2.1. Research methodology

2.1.1. Data used

The main data source used in this study is MODIS satellite images taken during the dry season from January to December in Ninh Thuan province in the years 2000, 2005, 2010, 2015, 2020, and 2022. The details of the MODIS imageries used in this study are described in Table 1.

Table 1. MODIS data used in drought assessment in Ninh Thuan province

ID	Data types	Satellite sources	Spatial resolution	Usage
1	Surface Temperature	MOD11A2.061 Terra Land Surface Temperature and Emissivity	250m	TCI Calculation
2	Vegetation Index	MOD13Q1.061 Terra Vegetation Indices 16-Day Global 250m	250m	VCI Calculation
3	Land cover	MCD12Q1.061 MODIS Land Cover Type Yearly Global 500m	500m	Extraction of agricultural land area

The land surface temperature data is obtained using MOD11A2.061 - MODIS/Terra Land Surface Temperature and Emissivity, with moderate temporal resolution of 8-day and a spatial resolution of 250 m. MODIS vegetation indices, produced on 16-day intervals and at multiple spatial resolutions, provide consistent spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll, and canopy structure. The study has used the MOD13Q1.061 Terra Vegetation Indices 16-Day Global products with 250m spatial resolution for the extraction of the Normalized Different Vegetation Index (NDVI). In addition, the land cover data extracted from the MCD12Q1.061 MODIS Land Cover Type Yearly Global 500 m was also used for the evaluation of drought impact on agriculture in Ninh Thuan province.

2.1.2. Study area

Ninh Thuan belongs to the South Central Coast region of Vietnam, bordering Khanh Hoa province to the north, Binh Thuan province to the south, Lam Dong province to the west, and the East Sea. The natural area of Ninh Thuan province is 3,358 km^2, including 01 city and 6 districts. Phan Rang - Thap Cham city is the political, economic, and cultural center of the province, which is 350 km from Ho Chi Minh City, 60 km from Cam Ranh airport, 105 km from Nha Trang city and 110 km from Da Lat city, convenient for socio-economic development exchanges (Figure 1).

This is the area with the highest temperature in the territory of Vietnam. The average temperature is about 27.10 and the total annual temperature is over 9400^{0}C. The average monthly temperature ranges from 24.6^{0}C (January) to 29^{0}C (May), making this area always receive a large amount of solar radiation around the year [10]. The average annual relative humidity is low; the coastal area (Phan Rang) has an average annual relative humidity of 71%, which is the lowest humidity in the country. The period with the lowest humidity is January to March. The months with the highest humidity are September to November. The difference between the wettest and driest months is from 12% to 16%. The average annual rainfall reached over 1300mm in the northern part, and gradually decreased to below 1000 mm in the southern part. Phan Rang is the driest area in the country, having an average annual rainfall of less than 800mm/year [10]. In addition, rainfall is mainly concentrated in 3 to 4 months (from September to December), and it is still continuously dry from January to May, causing a long dry season in the study area.

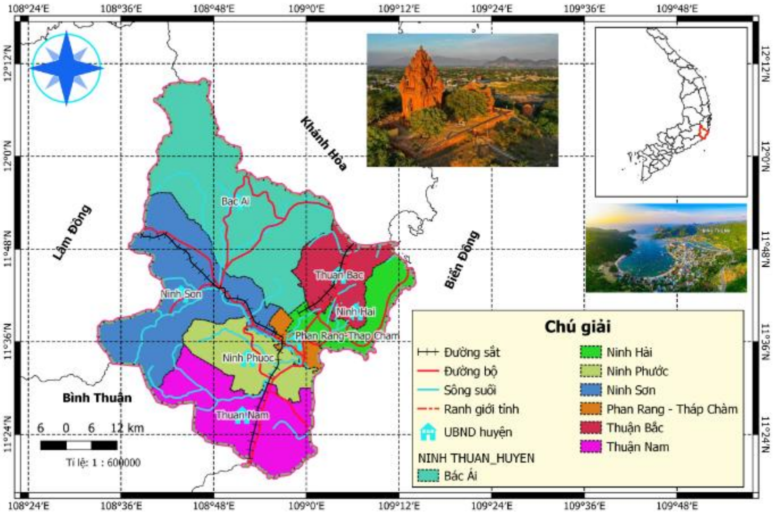


Figure 1. Map of the geographical location of Ninh Thuan province

2.2. Research workflow

To assess drought occurrence in Ninh Thuan province, the authors employed a methodology centered on the drought index. We analyzed the Vegetation Health Index (VHI) using the Temperature Condition Index (TCI) and the Vegetation Condition Index (VCI), which were calculated based on Land Surface Temperature (LST) and NDVI values derived from MODIS data. Most of the data processing steps are conducted on the cloud-computing Google Earth Engine (GEE) platform (*https://earthengine.google.com*). The analysis involved filtering data specific to Ninh Thuan province using the Map.addLayer command to display the boundaries, along with Map.centerObject to focus on the study area. The LST and NDVI data were filtered for the following years: 2000, 2005, 2010, 2015, 2020, and 2022.

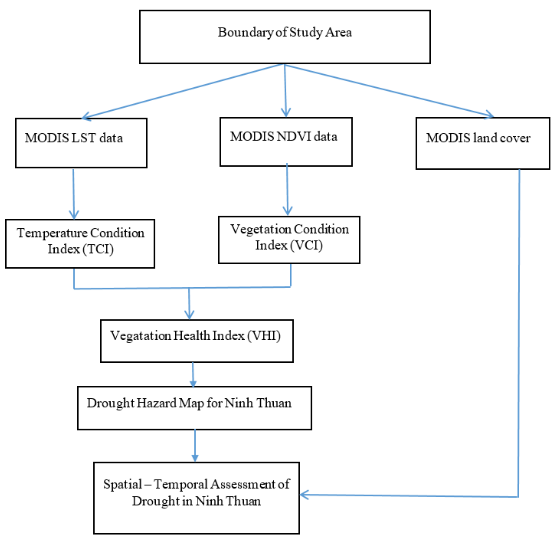


Figure 2. Flowchart of data processing

The process for conducting drought assessment research using remote sensing data is illustrated in Figure 2 below. The LST and NDVI data were filtered according to specific months of the year and focused on the Ninh Thuan area. Subsequently, the Temperature Condition Index (TCI), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI) were calculated using command codes in the New Script window on the GEE platform. This process allowed for the extraction of the VHI drought index, leading to the generation of a drought hazard map based on VHI, organized by month and according to the specified research years. Subsequently, the authors exported the data to Google Drive using the Export.image.toDrive command and processed it in QGIS 3.34 software. As a result, the drought hazard maps based on VHI by years have been generated and used for analyzing the drought variations in Ninh Thuan province.

From these drought hazard maps, the authors have identified areas experiencing severe and extreme drought, enabling the proposal of timely and effective solutions to adapt to and mitigate the adverse effects of drought on Ninh Thuan province and its residents. The research results provide a scientific foundation for analyzing drought developments in the period from 2000 to 2022 in Ninh Thuan, utilizing remote sensing techniques based on GEE technology and MODIS satellite data. Figure 2 below illustrates the data processing workflow used in assessing drought hazards in Ninh Thuan province.

2.3. Data collection and remote sensing images processing using Google Earth Engine

2.3.1. Extraction of the LST surface temperature index for the period 2000-2022

Land Surface Temperature (LST) is an important indicator of energy balance on the Earth's surface, reflecting the interactions and energy exchanges between the Earth and the atmosphere. The correlation between surface temperature and vegetation types provides essential insights for identifying drought conditions and pest outbreaks, contributing to the enhancement of environmental quality. This relationship serves as a scientific foundation for drought warnings and effective land use planning. MODIS (Moderate Resolution Imaging Spectroradiometer) features daily collection capabilities, offering high-frequency territorial observations and extensive coverage. This allows for the rapid, synchronous, and objective collection of information, making it well-suited for monitoring forest cover and development. LST and other dry indices can be effectively calculated using MODIS satellite images.

LST data extracted from MODIS satellites is obtained through the Google Earth Engine (GEE) platform. This data is processed to calculate average values over specified periods and spatial areas using functions available in the GEE library.

2.3.2. Extraction of NDVI index for the period 2000-2022

The Normalized Difference Vegetation Index (NDVI) was developed to investigate vegetation health conditions that are related to soil moisture levels. NDVI can be used as one of the conditions for drought monitoring. However, a single vegetation index cannot comprehensively reflect surface conditions. NDVI primarily reflects the green index, indicating vegetation vitality and chlorophyll content, rather than directly measuring the moisture status of the area.

The NDVI is calculated according to the following equation [11]:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

where NIR is the Near-infrared band and RED corresponds to the red band of satellite images. NDVI value ranges between [-1, 1] with the higher values representing the density of vegetation in the study area. NDVI is also used to determine the ecological and sustainable development of the environment. NDVI data extracted from MODIS satellite imagery is also collected through the GEE application and thereby applied for the further calculation of drought indicators for Ninh Thuan province.

Regarding the land-cover remote sensing data for the period 2000-2022, the author uses the function ee.ImageCollection on GEE with MODIS data MCD12Q1 and extraction of agricultural-related areas to assess the impact of drought in agriculture in Ninh Thuan province.

2.3.3. Extract remote sensing indicators

This study primarily focuses on drought hazard mapping using an indicator-based approach. The drought indices selected for this research include the Temperature Condition Index (TCI), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI). The current drought indices, including the Vegetation Health Index (VHI), Palmer Drought Severity Index (PDSI), and Standardized Precipitation Evapotranspiration Index (SPEI), all take into account factors such as temperature, precipitation, and water balance [12]. However, VHI incorporates vegetation information, making it particularly effective for detecting drought conditions related to vegetation compared to other indicators [13]. The fundamental principles behind the VHI are as follows:

- Poor vegetation health is characterized by low values of the Normalized Difference Vegetation Index (NDVI) and high Land Surface Temperature (LST). In contrast, good vegetation health is indicated by high NDVI values and increased greenness [2].

- The contribution of VCI and TCI to VHI is similar, as there are no data on the relative contribution of plants and temperature conditions to vegetation health [13].

Numerous research papers globally, including those in Vietnam, have utilized the three indices – VCI, TCI, and VHI to assess drought hazard. Such studies include:

Kafy et al. (2023) have used remote sensing techniques using satellite imagery that can play an influential role in determining the severity of drought [5]. This study aims to assess and predict the likelihood of drought using Landsat satellite imagery from 1996 to 2023 and a number of drought hazard assessment indicators, including the Normalized Different Vegetation Index (NDVI), the Modified Normalized Differential Water Index (MNDWI), Soil Moisture (SMC), Temperature Condition Index (TCI), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI). VHI has been used to determine and predict terms based on VCI and TCI characteristics for 2026 and 2031 using the Artificial Neural Network (ANN) - Cellular Automata (CA) algorithm. The results show that the increasing drought severity pattern is accelerated by a decrease in healthy vegetation (19%) and surface water bodies (26%) and a higher temperature increase (>5°C) between 1996 and 2021. In addition, the VHI results represent a large increase in extreme drought conditions from 1996 (2 percent) to 2021 (7 percent). Drought severity is predicted to see a possible increase in extreme and severe drought conditions in 2026 (15% and 13%) and 2031 (18% and 24%).

Gidey et al. (2018) studied drought monitoring that has been conducted in Africa in general and Ethiopia in particular. However, these studies were conducted using the limited capabilities of drought indicators such as NDVI, VCI, and TCI. To overcome this challenge, the current study aims to analyze the termination, duration, frequency, severity, and spatial distribution of long-term drought based on remote sensing data using the Vegetation Health Index (VHI) over a 3-month period in Raya and the surrounding region, Northern Ethiopia [2].

**** TCI***

The Land Surface Temperature (LST) derived from the thermal radiation bands is a good indicator of the energy balance of the Earth's surface, as temperatures can rise rapidly under water pressure. TCI is an early indicator of water stress and drought. It is calculated by the following formula [12].

$$TCI = \frac{(LST_{\max} - LST)}{(LST_{\max} - LST_{\min})} \times 100 \tag{2}$$

in which $LST_{\max}$ is the maximum LST value for many years in a multi-year dataset; $LST_{\min}$ is the minimum LST value in a multi-year dataset; LST is the land surface temperature value for the current month.

**** VCI***

VCI is an indicator of plant cover status as a function of the minimum and maximum levels NDVI encounters for a given ecosystem over many years. It is a better indicator of water stress than NDVI. Deviation of plant conditions is a measure of how much drought affects plant growth. VCI is calculated according to the following formula [14]:

$$VCI = \frac{(NDVI - NDVI_{\min})}{(NDVI_{\max} - NDVI_{\min})} \times 100 \tag{3}$$

where $NDVI_{\max}$ is the maximum NDVI value for many years; $NDVI_{\min}$ is the minimum NDVI value for many years, and NDVI is the NDVI value of the current month.

**** VHI***

VHI is a combination of VCI and TCI built and can be used effectively for drought assessment. It can be calculated by the following formula [15].

$$VHI = \alpha \times VCI + (1 - \alpha) \times TCI \tag{4}$$

in which α is weighted to measure the contribution of VCI and TCI to drought status assessments. Generally, α is set to 0.5 because it is difficult to distinguish the contribution of surface temperature and NDVI when measuring drought stress.

While numerous drought indices derived from remote sensing data have been developed, the Vegetation Health Index (VHI) has shown superior capability and suitability in detecting drought conditions [12-16]. VHI is a remote sensing index that combines information about vegetation condition and moisture availability. By combining VCI and TCI, VHI typically integrates the Normalized Difference Vegetation Index (NDVI) and land surface temperature (LST) [15]. VHI is used to assess vegetation health, indicating how well vegetation is performing under current environmental conditions [16]. During drought conditions, plants experience water stress, leading to decreased photosynthesis and reduced vegetation health. This is reflected in lower VHI values [12]. The relationship between Vegetation Health Index and drought hazard is crucial for understanding vegetation responses to water stress. By monitoring VHI, researchers and policymakers can effectively assess drought impacts, implement early warning systems, and develop strategies for managing ecosystems in drought-prone areas.

- By establishing threshold values for VHI, researchers can categorize drought levels, enhancing the understanding of how vegetation responds to varying degrees of water stress. Drought levels can be classified from severe to non-drought according to VHI values as shown in Table 1.

Table 1. Classification of drought levels according to VHI values

No.	VHI Value	Drought severity
1	0 - 10	Extreme drought
2	10 - 20	Severe drought
3	20 - 30	Moderate drought
4	30 - 40	Mild drought
5	> 40	No drought

Source: [15]

The study has effectively employed remote sensing methods to develop a drought database, providing valuable data to supplement the currently limited ground measurement stations in Vietnam.

2.4. Results and discussions

2.4.1. Drought risk assessment based on VHI index

The values of the Vegetation Health Index (VHI) are calculated by summing up both the VCI and TCI values used to assess the drought risk for Ninh Thuan province [15]. It is significant in representing vegetation health and vegetation stress that predominates in the study area. VHI values have been classified into five categories, such as extreme drought (0-10), severe drought (10-20), moderate drought (20-30), mild drought (30-40), and no drought (>40) (Table 1). Subsequently, the annual spatio-temporal analysis of drought hazard based on VHI is carried out for the period from 2000 to 2022 (Figure 3). It is obvious to observe from Figure 3 that the drought-prone area has been increasing gradually since 2000 and has become dominant in 2005, with the drought levels ranging from moderate to extreme, occupying an area of 187,724.75 ha, and equal to 56 percent of the study area (Table 2).

The areas predicted to have a low risk of drought are primarily located in the western districts, deep inland, where forest cover is prevalent, such as Bac Ai and Ninh Son. In contrast, regions frequently experiencing extreme and severe drought are concentrated along the coast, including Phan Rang, Ninh Hai, Ninh Phuoc, and Thuan Nam. This distribution can be attributed to the region's complex terrain, which gradually slopes from west to east, featuring mountains, hills, coastal plains, and the sea. The coastal plains are relatively narrow, bordered by low hills, and finally blocked by the eastern slope of the Truong Son range. The high mountainous terrain, ranging from 500 to 2,000 meters in the west and with slopes exceeding 25 degrees, constitutes about 62% of the total area, resulting in poor water storage capacity. This leads to a higher likelihood of water shortages and droughts, particularly in the eastern coastal areas. Notably, in the years 2005 and 2015, instances of extreme drought (VHI < 10) and severe drought (VHI 10-20) were observed, largely influenced by El Niño events. The VHI-based drought maps in Figure 3 indicated that most parts of the study area were affected during these periods.

In general, the areas at risk of severe and extreme drought increased very sharply in 2005, 2015, and 2020 (Table 2) and were mainly concentrated in areas of agricultural production land and sandy soil. In 2000 and 2022, the areas at risk of extreme and severe drought accounted for a low proportion, and conversely, the areas with mild and no drought accounted for the majority, and the rest of the areas in 2010 had severe and moderate drought. Thus, the phenomenon of drought in Ninh Thuan tends to be more and more intense, seriously affecting the living environment and production activities of people. The results obtained in the study also show the important role of land cover in reducing drought risk.

Table 2 illustrates significant fluctuations in the dry area of Ninh Thuan province over the years. In 2005, there was a notable increase in the area affected by severe drought, with 16,729.30 hectares classified as extreme drought and 75,594.55 hectares as severe drought. Conversely, 2022 recorded the lowest drought area, with only 265.06 hectares of extreme drought and 8,231.39 hectares of severe drought (Table 2). Comparing these two years reveals that the extreme drought area in 2005 was 63.1 times greater than in 2022, while the severe drought area was 9.2 times larger. These findings highlight that drought remains a significant concern for Ninh Thuan province, which experiences frequent and intense drought conditions that affect a substantial portion of its land area each year.

Table 2. Statistics on drought area in Ninh Thuan province from the VHI drought index in the period 2000 - 2022 (Unit: ha)

Drought Level	**Year**					
	2000	***2005***	***2010***	***2015***	***2020***	***2022***
Extreme drought	390.31	16,729.30	670.15	2,411.33	2,547.77	265.06
Severe drought	8,423.29	75,594.55	20,124.35	36,320.17	35,175.82	8,231.39
Moderate drought	50,612.45	95,400.90	80,035.12	88,359.94	91,602.22	53,130.96
Mild drought	138,612.65	106,513.64	135,968.34	116,287.28	117,718.84	117,481.91
No drought	137,255.52	40,676.25	98,098.25	91,491.72	87,877.35	155,783.24

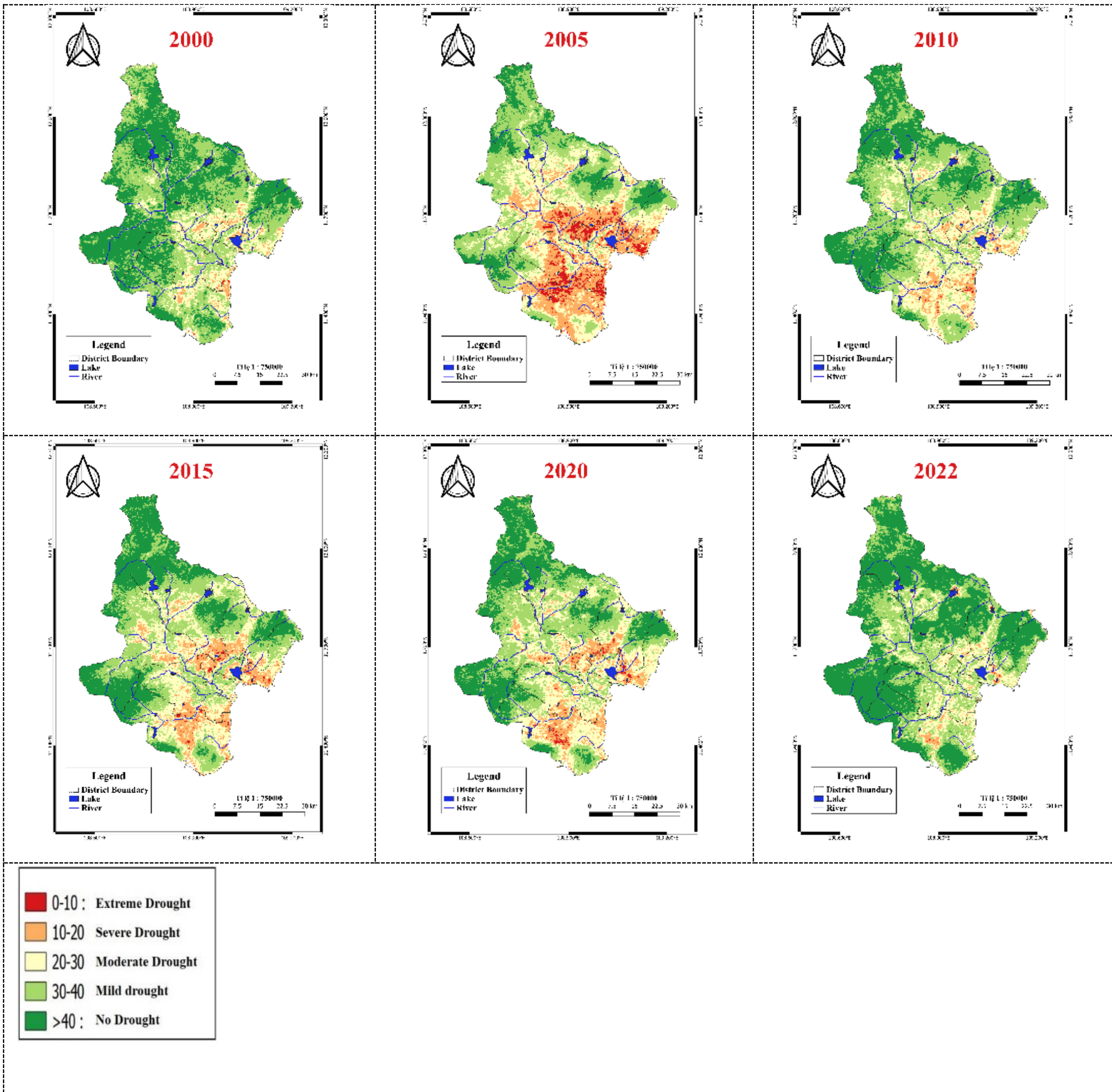


Figure 3. Map of the spatial distribution of drought-affected areas based on the VHI drought index in Ninh Thuan in the period 2000 - 2022

Spatially, the terrain in Ninh Thuan province is quite complex, resulting in an uneven distribution of drought levels. Severe and extreme drought conditions are primarily found in the coastal plains, particularly in the districts of Thuan Bac, Thuan Nam, Ninh Hai, Ninh Phuoc, and Phan Rang - Thap Cham (Figure 3). In contrast, drought intensity decreases in the western districts, such as Bac Ai and Ninh Son. In recent years, the impacts of climate change have exacerbated the drought situation in Ninh Thuan, significantly affecting the province's socio-economic conditions and environment.

2.4.2. Assessment of drought impact on agricultural land in Ninh Thuan province

In order to assess the impact of drought hazard on agricultural land in Ninh Thuan province, the study has taken the MODIS-derived land cover map that is freely accessible on GEE, and extracted the agricultural types for further analysis. Using the spatial analysis tools in GIS, the authors have overlaid the VHI-based drought hazard map with the agricultural land cover map to extract the agricultural areas affected by drought hazard in Ninh Thuan province. The results are shown in Figure 4 and Table 3.

Figure 4. Spatial distribution map of drought areas on agricultural land in Ninh Thuan in the period 2000 – 2022

Table 3. Drought level in the agricultural area based on the VHI drought index of Ninh Thuan province in the period 2000-2022 (*Unit: ha*)

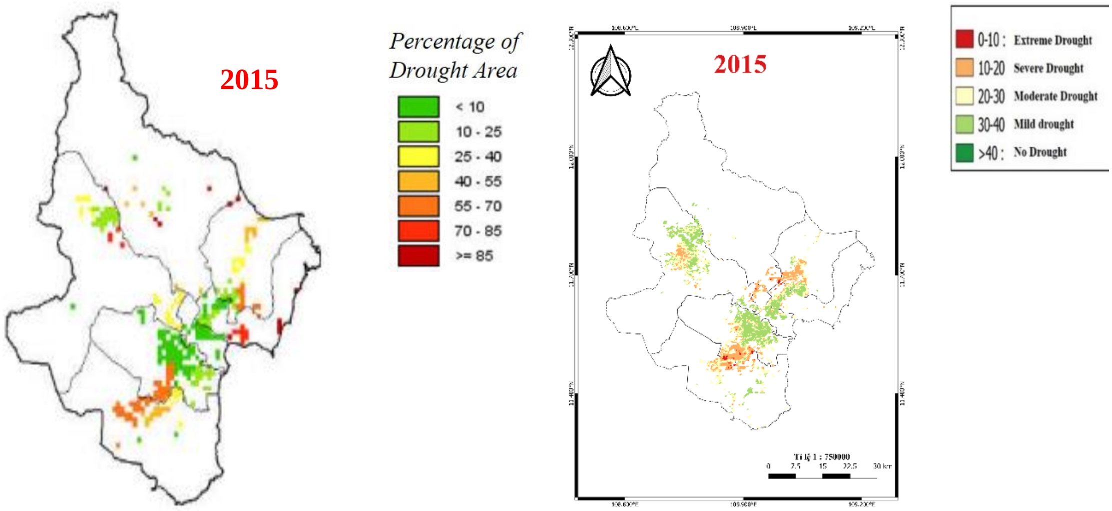
Drought level	Year					
	2000	***2005***	***2010***	***2015***	***2020***	***2022***
Extreme drought	0	2,878.5	25.6	532.3	413.2	0
Severe drought	854.1	10,860	3,521.2	9,423.8	7,841.2	823.2
Moderate drought	5,863.6	7,550.6	15,416.2	16,635.5	15,273.2	13,994.4
Mild drought	10,678.1	2,001.4	7,327.2	14,663.1	11,996.1	17,445.6
No drought	195,3	11	16	98,3	192,4	692,5

Table 3 and Figure 4 reveal that the areas impacted by moderate to severe drought in Ninh Thuan province constitute a significant portion of all agricultural land, ranging from 38% to 91%. The years identified as experiencing the most severe drought conditions were 2005, 2015, and 2020, with extreme drought areas measuring 2,878.5 hectares (12.35%), 532.3 hectares (1.29%), and 413.2 hectares (1.16%), respectively (Table 3). Consequently, a substantial portion of agricultural land in the province has been severely affected by moderate to extreme drought (Figure 4). These findings indicate that agricultural lands are particularly vulnerable to drought due to limited vegetation cover and seasonal concentration. Therefore, it is essential to prioritize appropriate measures to mitigate drought impacts. Local authorities should focus on effective irrigation planning, creating fields that enhance soil water retention, and selecting drought-resistant crop varieties. Additionally, constructing new irrigation systems and upgrading existing ones is both feasible and practical in the current context of climate change.

2.4.3. A comparison of the drought hazard map in Ninh Thuan province to other studies

Given the limited data available for testing and evaluating the accuracy of this research, the authors have chosen to focus primarily on extracting the VHI drought index from Google Earth Engine and creating a drought hazard map for Ninh Thuan province. This map was then compared to the drought map in Ninh Thuan in 2015 based on the VHI drought index published by Nguyen Duc Minh et al. (2018) for validation at a relative level [17].

Compared with the map established by the authors, the drought map of Nguyen Duc Minh et al. (2018) shows relatively consistent results. Accordingly, the study determined that two districts with moderate to extreme drought areas occupy almost the entire area, followed by Ninh Phuoc and Thuan Nam districts, located in the South, and the mild drought to no drought areas located in the North of the study area (Figure 5). The findings indicate that the results from this study on assessment of drought hazard in Ninh Thuan province are entirely practicable, exceptionally precise, and reliable.



(a) Drought map in 2015 published by [17]

(b) Drought hazard map generated by authors

Figure 5. Comparison of the developed drought hazard map to the reference study

3. Conclusions

This study investigated different drought indices, including the Temperature Condition Index (TCI), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI), through a series of processing steps on Google Earth Engine (GEE). These indices were extracted to create a drought hazard map for Ninh Thuan and to analyze the areas most susceptible to drought within the province's agricultural lands. The results highlight the effectiveness of integrating remote sensing and GIS technology for providing an objective assessment of the drought situation in Ninh Thuan province.

The study's results indicate that the years identified as experiencing severe drought include 2005, 2015, and 2020. Drought conditions are widespread across Ninh Thuan province, influenced by the complexity of the terrain, with severity varying from east to west. Areas most heavily impacted by drought are concentrated in the coastal plains, particularly in the districts of Thuan Bac, Thuan Nam, Ninh Phuoc, Ninh Hai, and Phan Rang-Thap Cham city, while drought severity decreases in the districts of Bac Ai and Ninh Son.

The research findings provide valuable and timely information that can assist managers in effectively planning, protecting, and sustainably managing land resources in Ninh Thuan province. By analyzing the patterns and severity of drought conditions, decision-makers can take proactive steps to safeguard agricultural productivity and enhance the resilience of local ecosystems. Moreover, these insights can inform the development of targeted strategies to mitigate the negative impacts of drought on agriculture, including optimizing water usage, selecting drought-resistant crop varieties, and improving irrigation techniques. In addition, the findings can support community engagement and awareness initiatives, equipping local farmers with the necessary knowledge and resources to adapt to evolving climatic conditions.

REFERENCES

[1] Vicente-Serrano SM, Beguería S & López-Moreno JI, (2010). A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. *Journal of Climate*, 23, 1696-1718, https://doi.org/10.1175/2009JCLI2909.1, 2010.

[2] Gidey E, Dikinya O, Sebego R, Segosebe E & Zenebe A, (2018). Analysis of the long-term agricultural drought onset, cessation, duration, frequency, severity, and spatial extent using vegetation health index (VHI) in Raya and its environs, northern Ethiopia. *Environmental Systems Research*, 7(1). https://doi.org/10.1186/s40068-018-0115-z.

[3] Rowhani P, Salakpi E, Bowell A, Tran M & Oliver S, (2022). Forecasting Agricultural Drought Using VCI and VHI across Africa. https://doi.org/10.5194/egusphere-egu22-8549.

[4] Zeng J, Zhou T, Qu Y, Bento VA, Qi J, Xu Y, Li Y & Wang Q, (2023). An improved global vegetation health index dataset for detecting vegetation drought. *Nature News*. https://www.nature.com/articles/s41597-023-02255-3.

[5] Kafy AA, Bakshi A, Saha M, Faisal AA, Almulhim AI, Rahaman ZA & Mohammad P, (2023). Assessment and prediction of index-based agricultural drought vulnerability using machine learning algorithms. *Science of Total Environment*, 867,161394. doi: 10.1016/j.scitotenv.2023.161394. Epub 2023 Jan 10. PMID: 36634773.

[6] Orimoloye IR, Belle JA & Ololade OO, (2021). Drought disaster monitoring using MODIS derived index for drought years: A space-based information for ecosystems and environmental conservation. *Journal of Environmental Management*, 284, 112028, https://doi.org/10.1016/j.jenvman.2021.112028.

[7] Niu K, Qiu J, Cai S, Zhang W, Mu X, Park E & Yang X, (2022). Use of a MODIS Satellite-Based Aridity Index to Monitor Drought Conditions in the Pearl River Basin from 2001 to 2021. *ISPRS International Journal of Geo-Information*, 11(11), 541. https://doi.org/10.3390/ijgi11110541.

[8] Szewczak K, Łoś H, Pudełko R, Doroszewski A, Gluba Ł, Łukowski M, Rafalska-Przysucha A, Słomiński J & Usowicz B, (2020). Agricultural Drought Monitoring by MODIS Potential Evapotranspiration Remote Sensing Data Application. Remote Sensing, 12(20), 3411. https://doi.org/10.3390/rs12203411.

[9] Kumar L & Mutanga O, (2019). Google Earth Engine Applications. MDPI - Multidisciplinary Digital Publishing Institute.

[10] Ninh Thuan Province's Statistical Office, (2022*). Natural conditions of Ninh Thuan province*. Statistical Publishing House.

[11] Weier J & Herring D, (2000). *Measuring Vegetation (NDVI & EVI*). NASA Earth Observatory, Washington DC.

[12] Sivakumar MVK, Motha RP, White DA & Wood DA, (2011). Agricultural drought indices. Proceedings of an expert meeting, *World Meteorological Organization* 2011, Spain.

[13] Kogan FN, (2001). Operational space technology for global vegetation assessment. *Bulletin of the American Meteorological Society*, 82(9), 1949-1964.

[14] Liu WT, & Kogan FN, (1996). Monitoring regional drought using the Vegetation Condition Index. *International Journal of Remote Sensing*, 17, 2761-2782.

[15] Kogan FN, (1995). Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*, 15(11), 91-100.

[16] Wang H, Lin H & Liu D, (2014). Remotely sensed drought index and its responses to meteorological drought in Southwest China. *Remote Sensing Letters*, 5(5), 413-22.

[17] Nguyen DM, Ha HD & Nguyen MT, (2018). Building the agriculture drought monitoring system using satellite data, case study in Ninh Thuan province, Vietnam. *Journal of Science and Technology Water Resources*, (50), 1-7 (in Vietnamese).